

Dissertation Title:

**Waveform capnography in the South African prehospital setting:
Knowledge assessment of qualified advanced life support
paramedics.**

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The above research was completed in partial fulfilment of the MPhil Degree in Emergency
Medicine at the University of Cape Town.

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DECLARATION

This research is based on independent work performed by Craig Alexander Wylie and neither the whole work nor any part of it has been, is being, or is to be submitted for another degree in this or any other university.

Signature:

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Glossary

ALS: Advanced Life Support

CO₂: Carbon Dioxide

CPR: Cardiac Pulmonary Resuscitation

Capnography: The graph visual depicted by end-tidal carbon dioxide.

Doctor: Medical Practitioner registered with the Health Professions Council of South Africa

ECP: Emergency Care Practitioner – A registration level with the health professions council for paramedics that are qualified with a degree.

EMS: Emergency Medical Services

ETCO₂: End-tidal carbon dioxide

ETT: Endotracheal Tube

HCO₃: Bicarbonate

HEMS: Helicopter emergency medical service

HPCSA: Health Professions Council of South Africa – statutory body for registration

ILCOR: International Liaison Committee on Resuscitation

OHCA: Out-of-hospital cardiac arrest

PaCO₂: Partial arterial pressure of carbon dioxide.

POCUS: Point of Care Ultra Sound

RSI: Rapid Sequence Intubation – The use of medication, normally including a paralytic, sedation and pain relief, to facilitate intubation.

ROSC: Return of Spontaneous Circulation

SCVO₂: Central venous oxygen saturation.

SPO₂: Peripheral capillary oxygen saturation.

Section A

Research protocol

Waveform capnography in the South African prehospital setting: Knowledge assessment of qualified advanced life support (ALS) paramedics.

Protocol 1.9 - August 2015

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Declaration:

I, Craig Wylie, hereby declare that the work contained in this assignment is my original work and that I have not previously submitted it, in its entirety or in part, at any university for a degree.

Signature:

Date: 20/08/2015

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Summary/Abstract

Although there is extensive literature regarding out-of-hospital use of capnography, the willingness and knowledge of South African paramedics where capnography is available for routine use is poorly understood. From informal reviews, it would appear that even when capnography is available the practitioners decided to not use the tool.

Aim: To determine the knowledge of prehospital providers with respect to the use of capnography to guide decision making in the treatment of patients.

Methods: A cross-sectional research-generated survey of 80 out-of-hospital advanced life support paramedic providers in South Africa working in the private industry where capnography is available. Participants will be recruited with the assistance of the company's research committee using an email platform, and consent process. The questionnaire will establish the knowledge, ability and willingness of advanced life support paramedics to identify and use capnography as part of their clinical decision making process. Descriptive statistics will be used to interpret and report the data. The study should be concluded within 6 months of receiving ethical approval from Human Research Ethics Committee of the University of Cape Town.

Discussion: The findings of the study will describe a cohort of out-of-hospital practitioners' knowledge and willingness to use capnography in an environment where it is routinely available. Recommendations will be made regarding the need for further policy development and change management for the implementation of best practice.

Background (Literature Review) & Rationale

Literature Review

Capnography, otherwise known as end-tidal carbon dioxide (ETCO₂) monitoring, had its inception into medicine in the late 1950s.¹ Waveform capnography is a visual representation of expired carbon dioxide that is generated as a metabolic by-product and dissolved in blood until it diffuses into the alveoli.² The 2010 American Heart Association (AHA) guidelines recommend waveform capnography use for the confirmation and continuous monitoring of endotracheal tube placement.³ This recommendation resulted in widespread procurement of waveform capnography-capable devices, without operational implementation.⁴ Capnography has been proven to be of value for the monitoring of multiple different physiological measures. These include; confirmation of tube placement, continuous monitoring for tube dislodgement, effectiveness of cardiac compressions, return (or loss) of spontaneous circulation, monitoring of ventilation, and haemodynamic stability.

INTUBATION

The ability of out-of-hospital practitioners to perform successful endotracheal intubation and subsequently recognise misplaced intubation was cited as early as 1984 and still remains a topic of concern in 2015.⁵ Most of these studies focus on the identification of misplaced endotracheal tubes on arrival at hospital.⁶ With the implementation of out-of-hospital capnography usage there has been a significant decrease in unrecognised oesophageal intubation.⁷ Some studies report a 0% rate of unrecognised oesophageal intubations when waveform capnography was used.⁶ Sensitivity and specificity have both been reported as high as 100% in the non-cardiac arrest patient, with sensitivity dropping to 67% in the cardiac arrest patient.⁸ The lower sensitivity in the cardiac arrest patient was ascribed to the lack of circulation.⁹ In a randomised control trial done on capnography for the recognition of simulated endotracheal tube dislodgement, it was seen that recognition of tube dislodgement is almost twice as fast when capnography is available compared to when it is not available.

CPR EFFICACY

Continuous monitoring of end-tidal carbon dioxide has also been shown to be a good indicator of effective performance of cardiopulmonary resuscitation, as it correlates with the cerebral perfusion pressure.¹¹ A systematic review done in 2013 reported that an ETCO₂ reading of less than 1.33 kPa (9.98 mmHg) was a strong predictor of mortality and higher than 1.33 kPa (9.98 mmHg) was associated with return of spontaneous circulation.¹² The review does discuss concerns regarding the methodology of all the studies, and that an overall outcome could not be reached.¹² Capnography can be used as an effective feedback tool during cardiac arrest. A decrease in ETCO₂ during CPR can be due to ineffective chest compressions.⁷ A sudden increase in ETCO₂ can, in a patient during CPR, indicate a return in spontaneous circulation.⁷ Conversely, if there is a sudden significant decrease in ETCO₂ level it may indicate loss of circulation.³ Practitioners can judge the change in a patient's cardiac output with a constant minute volume and a decreasing ETCO₂. This can be related to haemodynamic instability.¹³

VENTILATORY EFFICACY

Capnography can be used as part of the management strategy to aid decision-making on the mechanically ventilated patient. Because ETCO₂ is such a good predictor of PaCO₂ it also results in decreased need for frequent blood gas analysis.¹⁴ The identification of hypoventilation is much quicker, improving the timeliness of the intervention to correct the hypoventilation.¹⁵ In a large retrospective study looking at more than 16 500 patients, it was established that hypocapnia was associated with an increase in mortality, although this has little relevance on clinical practice.¹⁶ A decrease in ETCO₂ can be a result of hyperventilation, pulmonary embolism, cardiac arrest, hypotension, hypothermia or partial airway obstruction. In contrast an increase in ETCO₂ can mean that a patient is experiencing hypoventilation, rising body temperature, bronchospasm, or adrenergic discharge.²

WAVEFORM ANALYSIS

Changes in the shape of waveforms can give the practitioner an indication of the patient's condition and underlying problems like: Apnoea, bronchospasm, partial obstruction of the airway, gas leakage and more.¹⁷ Specific changes in the waveform are as follow:

Apnoea or obstruction will be evident with a flat line indicating no ventilation¹⁸

- Hyperventilation - decreased amplitude and width of waveform¹⁸
- Bradypnoeic Hypoventilation - increased amplitude and width¹⁸

- Hypopnoeic Hypoventilation - Decreased amplitude ¹⁸
- Physiological variability - varying amplitude and width ¹⁸
- Bronchospasm - normally increased amplitude with a shark fin appearance and a curved expiratory stage (which is as a result of slowed passage of air) and an up-sloping alveolar plateau stage (which is a result of the uneven emptying of the alveoli) ¹⁸

In the patient where an underlying ventilation and perfusion mismatch has been excluded, a deviation in ETCO₂ can be associated with metabolic disturbances. In a prospective study done by Kartal, they established that an ETCO₂ value of more than 37mmHg ruled out a bicarbonate level less than 21mmol/l. ¹⁹

SAFETY

Although the monitoring of ETCO₂ is generally safe; adverse events, false positive or false negatives do happen, understanding the possible errors in interpreting capnography is important. ²⁰ The cause of cardiac arrest, history of bystander CPR and time from arrest all influence on the initial ETCO₂ reading that is monitored during cardiac arrest. ²⁰ This is important to keep in mind when making a decision regarding probability of ROSC. ²⁰

AVAILABILITY (IN HOSPITAL)

A study published in the British Journal of Anaesthesia during 2011 reported that, despite the International Liaison Committee of Resuscitation (ILCOR) recommendation for the use of capnography on every patient and the widespread deployment of portable devices, it was available for as little as 68% of intubations. ²¹ ETCO₂ was also noted in this study to have been used in only 20% of general ward intubations, which is particularly important as this is an “uncontrolled” environment much like the environment that prehospital practitioners would practice in. ²¹ The study further discussed that one of the hospitals had a 100% compliance with the recommendation to use capnography for every patient. This illustrates that with an adequate change in management strategy it would be possible to employ the recommendation. ²¹

A 2014 study in the United States examined the reasons for capnography not being utilised when available in the acute setting. In certain cases staff champions were identified to promote the use of capnography. When these champions were not available it was perceived that utilisation decreased. ⁴ This indicated the need for a cultural change within the organisation. The other reasons seems more objective and might be easier to rectify in organisations, these including availability and accessibility of capnography, staff

understanding of the sound evidence behind the use of capnography, the impact on patient care, anecdotal experience with capnography, and the ability to interpret the information provided by the capnograph.⁴ If the same practitioner concerns exist in the South African setting, targeting these issues may result in an increase in utilisation of capnography when available.

AVAILABILITY (OUT-OF-HOSPITAL)

A large number of patients require out-of-hospital airway management.²² With the correct team and equipment this can be done safely in the out-of-hospital setting. The addition of ETCO₂ to the out-of-hospital arena has shown to be an effective and efficient method to provide safer care in both intubation and other treatment interventions performed.³ In one study done by Silvestri et al., it was identified that the omission of capnography by out-of-hospital practitioners increased the incidence of unrecognised misplaced intubations to 9%, as opposed to a 0% unrecognised intubations rate when it was used.⁶

When used correctly ETCO₂ can also assist prehospital providers to make diagnoses that would in other circumstance be difficult.²³ In a study done by Hunter, it was identified that ETCO₂ use can assist out-of-hospital practitioners in predicting congestive heart failure, yielding a sensitivity of 93% when using an ETCO₂ of <40mmHg for hypoventilation.²³

Motivation for Study

ETCO₂ monitoring in the intubated patient is a Class 1 recommendation by ILCOR since 2010. This is due to the proven ability of ETCO₂ to provide an objective measurement of endotracheal tube position, ventilation and circulation. Although not widely available in South Africa, ER24 (a private out-of-hospital care service) has provided the tool nationally to ALS paramedic vehicles and requires, per internal policy, the monitoring of ETCO₂ for all intubated patients. Following countrywide implementation over several years, ETCO₂ is now widely available to ALS practitioners in ER24 employment, but the question remains as to whether this costly tool is adequately utilised in the field.

Research Question / Hypothesis

In an out-of-hospital setting where waveform capnography is available, do ALS paramedics correctly interpret the results and use them to make appropriate decision making in the care of intubated patients? It is hypothesised that paramedics that have the modality available

would utilise the tool, however knowledge deficits would exist in the indications and interpretation of results.

Specific Aims

To describe the knowledge of waveform capnography by Advanced Life Support paramedics who currently have the tool available.

Objectives

The study will assess the knowledge and decision making of a cohort of ALS paramedics with access to out of hospital ETCO₂ monitoring around:

- I. Utilisation of ETCO₂ in the out of hospital environment when it is available
- II. Confirmation of endotracheal intubation & monitoring for accidental tube dislodgement.
- III. Efficacy of CPR and monitoring for Return of Spontaneous Circulation (ROSC).
- IV. Monitoring of mechanical ventilation (hypoventilation, hyperventilation, tube/circuit obstruction, bronchospasm).
- V. Optimisation of mechanical ventilation based on interpretation & targeting specific ETCO₂ (e.g. head injuries).

Methods

Study Design

This is a cross-sectional, research-generated survey of the practice of advanced life support out-of-hospital paramedics working for a private ambulance service in South Africa. The questionnaire will be administered utilising a web-based form after informed consent has been obtained.

Study population & Sampling

The study population will be advanced life support paramedics who are currently employed in one of the largest private ambulances services in South Africa (ER24). The service currently employs approximately 80 advanced life support paramedics across all provinces of South Africa who are involved in the clinical management of patients. The vast majority of these paramedics have access to waveform capnography. The study will attempt to reach all of the advanced life support paramedics employed by ER24. Survey questionnaires typically have a response rate of approximately 60%. Attempts will be made to increase this response rate through information on the study, and multiple reminders, but even a 60% sample of the 80 ALS providers will provide a sample of around 50 which will be adequate for the largely descriptive purposes of this study. The participants will be contacted by email (details provided by ER24, as outlined in Annexure A, inviting them to take part in the study.

Inclusion criteria

- Consenting advanced life support paramedics (including; critical care assistants, national diplomates and graduate paramedics).
- Employed at ER24 for a minimum of one month, as operational staff in clinical care.
- Registered with the Health Professions Council of South Africa (HPCSA), as either a Paramedic (which includes the Critical Care Assistant and National Diplomat paramedic) or Emergency Care Practitioner

Exclusion criteria

- Practitioners who do not have access to waveform capnography in clinical practice for more than 50% of shifts (established by initial statement and questions of the questionnaire)
- Practitioners who have not been clinically active in out of hospital operations for more than 3 months

Measurements

Responses will be assessed through a web-based survey platform (SurveyMonkey®). A structured literature review was done to generate a questionnaire (appendix B). The questionnaire will assess the knowledge of the cohort of respondents around their use of ETCO₂. Since this is an assessment of knowledge only, the validity of the questionnaire is not in question, but to assess the appropriateness and clarity of the questionnaire, the questionnaire content will be assessed and modified if necessary by an expert group of emergency physicians, senior paramedics and anaesthetists. A pilot will be done with five out-of-hospital providers to test the questionnaire for feasibility and comprehension. Any feedback given during this period will be assessed and used to assist in the understanding of the content, the changes will in no way change the objectives or methodology of the study.

The questionnaire is divided into four sections. Section one will record the demographics (gender, qualification, years of experience and work sector) of the participants. The second section investigates the participants' knowledge and willingness to use waveform capnography, by presenting a series of true or false questions. The third section provides a series of vignettes (patient scenarios and capnography tracings) in which the participant is required to choose the most appropriate from a predetermined list of options. The fourth section will allow the participant to elaborate, in free text, issues around the use or non-use of capnography.

Data management

Questionnaires will be distributed using a web-based platform (SurveyMonkey®) to practitioners meeting the above criteria for completion. Each study participant will be assigned a unique research identifier and only that identifier will appear on the electronic data sheets. Informed consent will be performed by use of an electronic declaration (see appendix A). Non-responders will be sent three reminder emails at weekly intervals. An SMS would also be sent to ensure that there was not a failure on the delivery of the email. The data will be kept in a password-protected file on a password-protected computer only accessible by the principal investigator. The electronic transcriptions will be kept for a period of 5 years.

Statistical Analysis

Data will be subjected to descriptive analysis. Demographic data will be presented as numbers, means, medians and standard deviations. Section two and three will be presented as percentage of correct answers per question. Associations between demographic data, knowledge based answers and treatment decisions will be investigated by chi-square analysis. Free text comments from Section 4 will require simple qualitative analysis, through transcription, thematic coding and analysis using basic qualitative techniques and software when necessary.

Ethical Considerations

Ethical approval will be sought from the Human Research Ethics Committee (HREC) of the University of Cape Town. Written approval from the private ambulance service, ER24, will be sought. Provisional approval has already been obtained in principal from the ER24 research liaison, pending approval by HREC. This approval will need to include, giving the researcher access to contact details of consenting employees who previously provided their details to ER24 for communication purposes. (Addendum 1) Permission will be sought from the ambulance service before using their name in any publication.

Informed consent will be obtained electronically via a declaration. (See Appendix A). The questionnaires will be distributed, after consent, to professionals who are all fluent, and use English on a daily basis in their employment. There is hence no reason for translation or the availability of a translation.

This research will be conducted in compliance with the Declaration of Helsinki, 2013. It can be regarded as minimal-risk research. All questionnaires will be anonymous, with no specific identifying data recorded. Confidentiality will be ensured and no information will be

disclosed. All data will be secure and password protected. Only the principal investigator and supervisors will have access to the raw data. There is no foreseeable risk or danger to participants, as confidentiality will be ensured.

The research will be self-funded by the principal investigator.

Limitations

External validity will be affected due to the fact that the study is only being done in one private ambulance service.

Causation cannot be established as the study is descriptive in nature and the methodology is not powered to reach such conclusions and looks at association rather than causation.

Limitations of self-reporting are noted as a potential bias due to inaccurate recall, deception, or the unavailability of the information to conscious processing.

Data Dissemination Plan

Stakeholders involved will receive a copy of this report including recommendations for education and standard operating procedures. If major knowledge deficits are identified a training programme will be set up to improve education on the topic. The study will also be written up in the format of a publishable article. Publication for this article will be sought with a relevant accredited journal. The analysis of the data will also be presented in a poster format for possible presentation at appropriate conferences.

Project Timeline (2015 – 2016)

2015	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB
EM-DRC	X	X								
Sx-DRC		X								
Ethics			X	X	X					
Data Collection						X				
Transcribing of Data							X			
Data Analysis							X			
Compilation of Final Report								X	X	
Submission									X	X

Resources & Budget

No specialised equipment will be required. The principal investigator will complete data collection and therefore salary for a research assistant is not required. The research is self-funded by the principal investigator.

April – December 2015				
Item	Description	Unit cost	N° of Units	Total cost
Consumables	Development of the research			
Printing paper	Paper for printing of compulsory documentation	80	1	80
Printing and photocopying	Copying and printing of the compulsory and any documentation that need to be stored.	300	1	300
Communication				
Internet	Vodacom is being used by the researcher at present	149/1g	2	298
Cell phone	Phone calls to supervisors and all other roleplayers	R1.00/min	500	500
WEBBASE PLATFORM				
Survey Monkey	Institutional Access	0	0	0
Personnel				
1. Statistician	To assist with data analysis	R500/hour	4	R 2000
Total				R 3178

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Section B

Literature review

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Background

Advanced life support (ALS) practitioners in South Africa are often called upon to perform lifesaving procedures during the acute phase of injury outside of health facilities. Interventions such as intubation and ventilation form part of the ALS paramedic scope of practice. To perform these interventions in a safe manner, ambulance services are continuously evaluating, procuring and implementing new technologies to improve patient safety.

South Africa has three broad levels of practice in the emergency medical services (basic, intermediate, and advanced); these do not differ between public or private industry. Practitioners can achieve advanced life support qualification in one of three ways: (1) a series of short courses will allow in-service progression, ultimately qualifying as ALS with a one year Critical Care Assistant course (CCA); (2) a tertiary qualification from a university will qualify practitioners with a national diploma (NDip) after three years; or (3) a bachelor's in emergency medical care (BTech/BEMC) after 4 years study. The scope of practice is regulated by the Health Professions Council of South Africa (HPCSA), such that a CCA and NDip may register on the paramedic register and a BTech/BEMC on the register for Emergency Care Practitioners (ECP).

ALS paramedics (CCA and NDip) are able to perform drug assisted intubation with deep sedation. They have access to morphine and midazolam available to facilitate the sedation of patients. ECPs (BTech/BEMC) are also equipped with the same medication as paramedics, but also have the ability to perform a Rapid Sequence Intubation (RSI) with an induction agent and paralytic agent. ECP scope of practice is however restricted with regards to the choice of medication they can use. Etomidate or ketamine can be used as induction agents and suxamethonium, rocuronium or vecuronium may be used as paralytics. The HPCSA has deemed the use of ETCO₂ and mechanical ventilation as mandatory when an RSI is being performed in the out-of-hospital setting¹

Capnography is a relatively new technology that has been made available to out-of-hospital providers in some settings within the last decade. Waveform capnography is an adjunct that can be used to assist in the safe performance of various procedures and to assist in the assessment of physiological status and effectiveness of ventilation in some contexts.

The current knowledge of out-of-hospital ALS practitioners around capnography is unknown in an environment where waveform capnography is increasingly available. Each university has their own curriculum, without standardisation of the training on capnography that ALS paramedics receive during their training. The HPCSA require each ECP to complete a logbook requiring 20 uses of capnography during their practical phase of training.² The HPCSA published the curriculum for CCA in 1998³, and to our knowledge this has not been updated, with no mention of capnography. In 2013⁴, the HPCSA published a document stating that an educational institution should have capnography available when they are accredited. Further to this, South Africa does not have a national board exam, which means that the knowledge of newly qualified paramedics is never truly tested independent of the institutional exams.

Objectives of Literature Review

An initial literature search was done to establish the knowledge that ALS paramedics have regarding waveform capnography. A restrictive search limited to the knowledge of EMS personnel on capnography yielded no results. The decision was then made to widen the search to the application of capnography in the emergency medical services and out-of-hospital setting.

The objectives of the literature review were aligned with the knowledge needed to achieve the objectives of the study:

- Establish the usage and analysis of capnography/ ETCO₂ in the out-of-hospital environment.
- Establish the usage of capnography for confirmation and monitoring of tube placement.
- Establish the role capnography during cardiac arrest.
- The role of capnography during ventilation.
- Highlight adverse events, limitations and other indications for capnography.

Inclusion Criteria

- Study Design: Systematic reviews, meta-analysis, randomized control trials, prospective studies, retrospective studies.
- Types of participants: Human
- All ages.
- Publication date: 2005-2016
- Language: English

Exclusion Criteria

- Study Design: Case Reports
- Non-study articles: Letters to the editor, Clinical practice guidelines

Quality Criteria

- Search strings were explored in Pubmed using University of Cape Town library access. The search titles and abstracts were read and scanned for relevance to the study objectives. The identified studies were reviewed based on the inclusion and exclusion criteria, after which the articles were listed and summarised in a table of evidence. Evidence was ranked based on study design and publication date. (Addendum A) The references from the identified articles were then examined for any other studies within the inclusion and exclusion criteria and these were added. Finally, local South African studies were sought by word of mouth and also included to show a comparison. Any studies older than 15 years were excluded. This period was chosen as most of the currently used resuscitation practices are based on changes made by ILCOR after the release of the 2000 resuscitation guidelines.⁵⁻⁷

Literature Search Strategy

A search was done of Medline (Institution access: University of Cape Town) for English language articles. The Medline search was deemed sufficient for the purposes of this literature review as it was likely to include most of the recent literature in this field. Six different search strings were used to identify studies that have relevance on the objectives of the literature review (see figure 1):

- **Search String 1:** ((capnography[MeSH Terms]) AND ((emergency medical services[MeSH Terms]) OR prehospital emergency care[MeSH Terms])) AND "analysis"[MeSH Subheading]
- **Search String 2:** ((capnography[MeSH Terms]) AND ((emergency medical services[MeSH Terms]) OR prehospital emergency care[MeSH Terms])) AND endotracheal intubation[MeSH Terms]
- **Search String 3:** ((capnography[MeSH Terms]) AND ((emergency medical service[MeSH Terms]) OR emergency care, prehospital[MeSH Terms])) AND ((arrest, cardiac[MeSH Terms]) OR cardiopulmonary resuscitation[MeSH Terms])
- **Search String 4:** (((emergency medical services[MeSH Terms]) OR prehospital emergency care[MeSH Terms])) AND capnography[MeSH Terms]) AND mechanical ventilation[MeSH Terms]
- **Search String 5:** ((capnography[MeSH Terms]) AND ((emergency medical services[MeSH Terms]) OR prehospital emergency care[MeSH Terms])) AND hemodynamic[MeSH Terms]
- **Search String 6:** ((capnography[MeSH Terms]) AND ((emergency medical services[MeSH Terms]) OR prehospital emergency care[MeSH Terms])) AND "adverse effects"[MeSH Subheading]

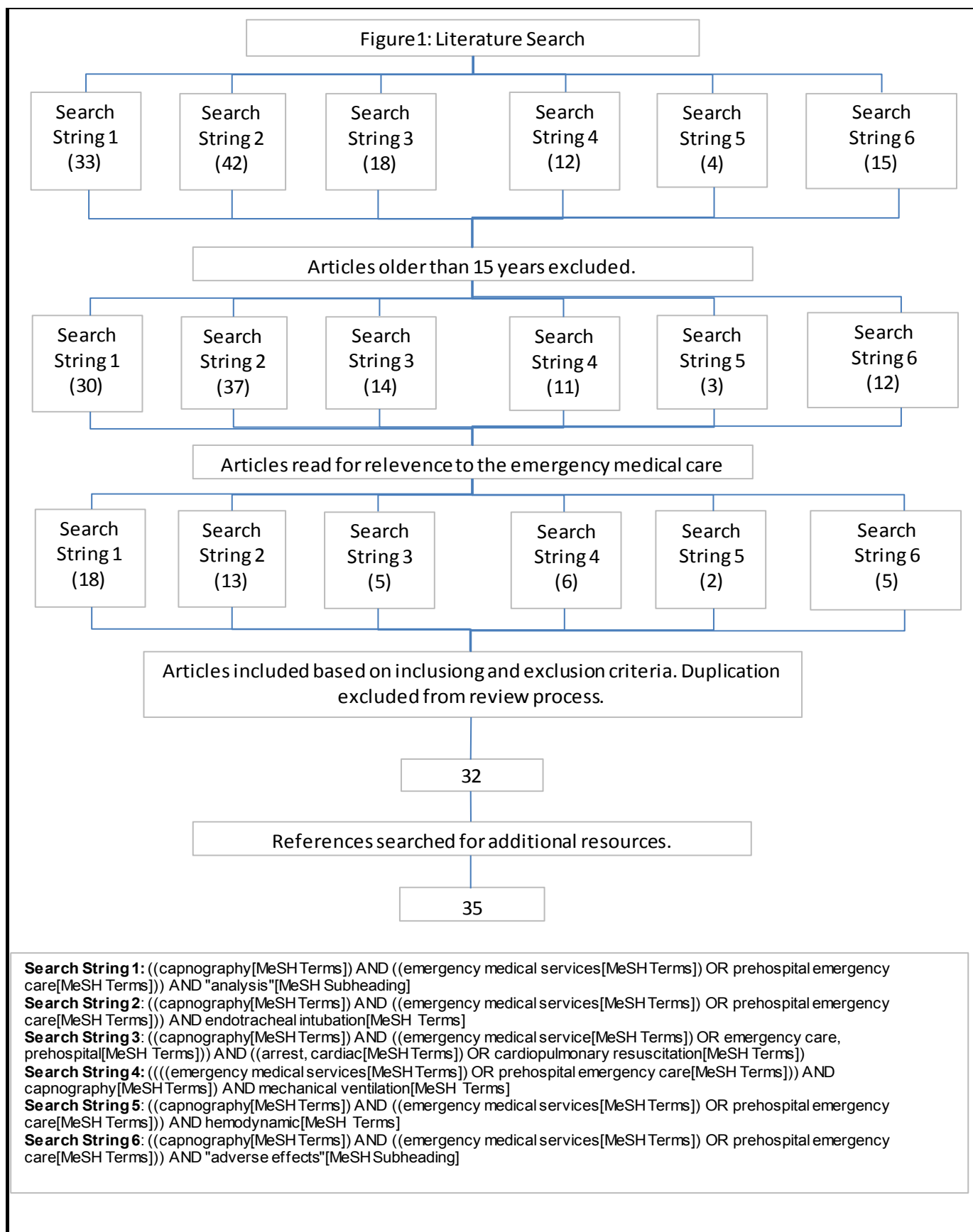


Figure 1 - Literature Search Strategy

Summary

Based on this search, to date (08 May 2016) there was no published literature on the Medline database, related directly to the knowledge of prehospital providers on waveform capnography. The review of relevant literature identified four broad areas of applicability of capnography in the out-of-hospital environment. In line with the literature review's objectives, the summary of evidence will assess confirmation of intubation, monitoring of cardiopulmonary resuscitation, assessment of ventilation and the limitations of capnography.

The literature will be cited followed by a summary related to the possible or current applicability in the South African out-of-hospital setting.

1) Confirmation of intubation

Several studies described the evidence for the availability and use of capnography during endotracheal intubation. The studies show that sensitivity and specificity for confirmation of Endotracheal Tube (ETT) placement by ETCO₂ is good,^{8 9} and that the use of ETCO₂ does shorten the time to recognition of tube displacement.¹⁰ Several studies were done around the international availability of ETCO₂ in the emergency situation.¹¹⁻¹⁷ There were also two studies that specifically looked at the availability and use of ETCO₂ in a South African setting.^{18 19} Limitations in the use of ETCO₂ for confirmation of intubation were also highlighted in some of the recent literature.²⁰

Confirmation of intubation is performed with waveform capnography after the placement of an ETT. The presence of a waveform or a value more than 0mmHg would confirm the correct placement of the ETT in the trachea.⁵

A meta-analysis by Li⁸ in 2001 explored the evidence available before 1999. Ten trials were included assessing: The number of tracheal intubations, the number of oesophageal intubations, and the sensitivity and specificity of capnography. A total of 2192 intubations were examined, 20% were assessed with infrared quantitative devices, while 80% were tested with colorimetric devices. The authors noted that most of the studies were underpowered, bringing into question the ability to apply the results outside of the study context; only one of the studies reported on both sensitivity and specificity. Many patients were in cardiac arrest, but not all studies reported on this or haemodynamically unstable patients as a subgroup. This meta-analysis reported the sensitivity and specificity of

capnography for confirmation of intubation as 93% (95% CI 92%-94%) and 97% (95% CI 93%-99%) respectively.⁸

A prospective study done by Grmec and Mally,⁹ compared three different methods for immediate confirmation of ETT placement in the out-of-hospital setting. They found that capnography (graphic representation of expired ETCO₂) and capnometry (numerical representation of expired ETCO₂) were equally effective and yielded a sensitivity and specificity of 100% (95% CI 94%-100%). Auscultation alone yielded a sensitivity of 94% (95% CI 88%-98%) and a specificity of 66% (95% CI 58%-70%). The time difference comparison between using capnography and using auscultation reached statistical significance ($p < 0.05$). The authors concluded that ETCO₂ should be used as a supplement to auscultation for confirmation of ETT placement.⁹

During a simulated tube dislodgement scenario in 2011, Langan¹⁰ randomised paramedics and paramedic students to either have capnography available or not. Participants were recruited from either a training program (students) or continuous medical education sessions.¹⁰ The recruitment strategy would automatically exclude any paramedics who did not attend continuous medical education. The randomised control trial found that the time to recognition of tube displacement by participants with capnography was significantly shorter than that of the participants where it was not available ($p = 0.05$). Paramedics had a shorter time to correction than students ($p = 0.01$). In this study the authors did not find a statistically significant difference between years of experience, perceived comfort, training institution or previous use of capnography.¹⁰

Several authors have looked at the availability of capnography. Although there is limited evidence in the out-of-hospital setting, the in-hospital environment provided valuable insight on the availability of capnography especially in the out-of-theatre arenas.¹¹⁻¹⁷ Bowles et al.¹¹ performed a prospective study of out-of-theatre intubation in the United Kingdom. Overall they identified several factors that decreased the safety of patient care. Although capnography was strongly recommended in the guidelines, it was only used in 72% of intubations in the Intensive Care Unit (ICU) and 68% of overall intubations. When capnography was not used, 48% said that it was not available, and 31% said they forgot to use it.¹¹

Hansen et al.¹² did a retrospective analysis of the NEMISIS database in the United States in 2012. They found that ETCO₂ was only used during 36.8% of intubations and only 22.2% of these cases utilised quantitative capnography.¹² Similarly, another retrospective study in the United States looked at the outcome of patients receiving interventions, when in the

emergency centre for more than two hours, and found that only 5.9% of patients were monitored by ETCO₂.¹³

Shavit et al.¹⁴ established that amongst paediatric emergency physicians, 45% of them did not use capnography routinely following intubation to confirm ETT placement. Similarly, Langhan¹⁵ conducted a web-based survey of all paediatric emergency medicine fellowship programs, finding that ETCO₂ was available 88% of the time in intubated patients, 53% in non-intubated patients, but reported to be only used often by 20% of the population. Several reasons for non-use were noted, including: expense, perceived inaccurate measurement, lack of perceived need, lack of familiarity, and 65% responding that there was a lack of equipment.

Delorio¹⁶, through a US survey, showed that colorimetric devices were available 77% of the time and continuous monitoring 25% of the time, but the technology was only used 14% of the time, even when available.¹⁶ A Scottish survey identified that all emergency centres had capnography available, but 33% of respondents did not routinely use it.¹⁷

In South Africa, Botha¹⁸ and Wood¹⁹ both conducted postgraduate research around the availability and use of capnography. In 2004, Wood performed a survey distributed to doctors (22), nurses (22) and paramedics (5) working in emergency centres and the aeromedical environment in the Western Cape. He found that tertiary and private hospitals had capnography available most of the time (75%). However doctors only knew where it was stored in 50% of facilities. Knowledge was poor regarding the ability of ETCO₂ to confirm ETT placement, with a large proportion of doctors, nurses and aeromedical paramedics who did not believe it was a valuable tool (77%, 73% and 100% respectively).¹⁹

Botha in 2011 assessed misplacement during ETT out-of-hospital intubation. On arrival of a paramedic at a hospital, on-duty medical practitioners would mostly use clinical auscultation (97%), direct laryngoscopy (33%) and used capnography only 4% of the time to detect misplacement. With capnography being highly sensitive and specific with regards to ETT placement, it is important to note the infrequent use of the tool by medical practitioners for confirmation of ETT in this context. This could be a significant limitation of this study as the in hospital confirmation was not always performed using capnography. A total of 100 patients were recruited in the study at eight different hospitals. Only 19% of out-of-hospital intubations were confirmed using ETCO₂. There were two unrecognised oesophageal intubations, neither with ETCO₂ confirmation.¹⁸

Capnography is reliable in identifying ETT placement. It does however have the limitation that it is not able to identify deep ETT placement, with resultant bronchial intubation.²⁰

2) Monitoring of Cardiopulmonary Resuscitation

The evidence regarding the use of ETCO₂ during cardiopulmonary resuscitation is limited. In this focused literature search we establish that ETCO₂ can be used to establish when a patient in cardiac arrest has return of spontaneous circulation (ROSC).²¹ There may be limitations to using ETCO₂ to establish both quality of CPR and ROSC.²²

Capnography correlates with cardiac output and myocardial blood flow during CPR, thus making it possible for practitioners to monitor and improve the quality of CPR without interrupting compressions. An abrupt change of ETCO₂ can indicate either the loss of spontaneous circulation or the return of spontaneous circulation.⁶

Pokorna et al.²¹ in 2010 described a statistically higher ETCO₂ reading during resuscitation (CPR) after ROSC was achieved compared to before ROSC ($p < 0.0001$). The authors concluded that a sudden increase of ETCO₂ of about 10mmHg likely indicates ROSC.²¹

Grmec and Klemen,²³ investigated the utility of ETCO₂ as a prognostic tool for the initial outcome for a patient in cardiac arrest. They found that none of their study patients with an ETCO₂ of less than 10mmHg obtained ROSC. An initial ETCO₂ of more 10mmHg had a 100% sensitivity, 74.1% specificity, 55.6% positive predictive value and 92.1% negative predictive value for ROSC. In this study the authors did not report on the confidence intervals.²³

Heradstveit et al.²² looked at the factors that influenced the interpretation of capnography during the delivery of ALS CPR. They reviewed 575 patients retrospectively and found that capnography can be used to distinguish between a patient with or without ROSC for any initial rhythm and cause of cardiac arrest. However, there were several factors that would confound ETCO₂ interpretation during cardiac arrest: Respiratory arrest was associated with a higher ETCO₂ than cardiac arrest caused by cardiac aetiology, and pulmonary embolism was associated with lower initial values than both cardiac and respiratory cases. Initial levels of ETCO₂ were different for each presenting rhythm, asystole achieving ROSC giving the highest of all the readings. ROSC was however an independent variable in all the presenting rhythms.

Bystander CPR within four minutes of cardiac arrest saw higher levels of ETCO₂ and delayed measurement of ETCO₂ after cardiac arrest showed lower levels once measured.²²

3) Assessment of ventilation

Assessment of ventilation using ETCO₂ in an emergency care situation can be beneficial for various reasons. ETCO₂ is useful for identifying respiratory depression prior to signs of hypoxia seen with pulse oximetry.²⁴⁻²⁶ Ventilation is better optimized and maintained when capnography is employed.²⁷⁻²⁹ Several studies have proven a correlation between ETCO₂ and PaCO₂, however there are conflicting results around what differences exist between assessment using ETCO₂ and PaCO₂.³⁰⁻³⁶ One study examined the portability of ETCO₂ which is relevant to the prehospital environment.³⁷

Deitch et al.,²⁴⁻²⁶ performed three randomized control trials (RCT) looking at hypoxia during procedural sedation in an emergency centre situation. The latest study in 2010²⁶ found that all cases of hypoxia were identified by capnography before onset of respiratory depression. They found capnography to be 100% sensitive and 64% specific for the prediction of hypoxia. The addition of capnography in the emergency centre assisted the treating physician to identify respiratory depression before signs of hypoxia in a cohort of patients undergoing procedural sedation (with propofol in an emergency centre without supplementary oxygen administration).²⁵ An earlier study showed that treating physicians often missed respiratory depression that was identified by capnography in sedated patients (receiving midazolam and fentanyl) in the emergency centre.²⁴

In 2003 Helm et al.²⁷ assessed paramedics from a HEMS service who were either allowed to see the capnography monitor or blinded to the capnography monitor. Arterial blood gases were taken on arrival of the patient at hospital. It was found that 'normo-ventilation' was 63.2% in the group that had capnography vs. 20% in the group that did not have capnography available. There was specific evidence of more hypoventilation in the group that did not have capnography available. Both these findings were statistically significant, $p < 0.0001$.²⁷ Kober et al.²⁸ assessed the ability of ETCO₂ compared to SPO₂ as additional tools to monitor patients during out-of-hospital transport. The authors looked at patient satisfaction (no statistical difference; $p = 0.61$), practitioner satisfaction (no statistical difference), and alerts and malfunction (statistical significance; $p < 0.01$). It was seen that pulse oximetry had more alerts in total and for each patient. The total times of malfunction were also higher for pulse oximetry when compared to ETCO₂.²⁸

A retrospective study done by Caulfield et al.²⁹ reviewed 100 prehospital patient transfers to assess compliance with the *Brain Trauma Foundation* recommendation to maintain ETCO₂ between 30-35mmHg. They found that 65 patients (65%) were maintained at an ETCO₂ of more than 29mmHg, and 35 patient did not achieve the guideline. Patients who achieved the guideline had a 29% mortality, and patients who did not achieve the guideline had a 46% mortality rate. This finding however did not reach statistical significance. This study did

however demonstrate that out-of-hospital practitioners were able to monitor ETCO_2 and adjust ventilation accordingly.²⁹

The correlation between ETCO_2 and PaCO_2 is important when using capnography to optimise the ventilation of patients. There have been several studies in different population cohorts.³⁰⁻³⁶ Cinar et al.³⁰ examined the correlation between mainstream ETCO_2 and PaCO_2 in 162 patients presenting to the emergency centre who also required PaCO_2 analysis. The correlation was found to be good ($r=0.911$; $p<0.001$). Delerme et al.³¹ prospectively evaluated 43 patients with dyspnoea, admitted to one emergency centre. They found that although there was good correlation ($r=0.82$), the differences between the means was large.³¹ These two studies specifically looked at ETCO_2 compared to PaCO_2 monitoring in relation to dyspnoea. They found a correlation but also that there were sometimes large differences between the two measurements.

Jabre et al.³² reported that continuous capnography was easily performed during ambulance transport in 50 patients. Blood gas analysis failed in one of these patients, and agreement was poor between ETCO_2 and PaCO_2 with a mean difference of 12mmHg.³² The use of PaCO_2 and transcutaneous CO_2 monitoring in the out-of-hospital environment has been shown to be more accurate than ETCO_2 , but these modalities are harder to use and often not available.³³ In a prospective study by Belpomme et al.³⁵ they found a significant difference between ETCO_2 and PaCO_2 in the out-of-hospital scenario. They recommended that if tight control of ETCO_2 is needed for an out-of-hospital patient a portable blood gas should be used.³⁵

Tingay et al.³⁴ assessed the accuracy of ETCO_2 during transportation against transcutaneous and arterial CO_2 monitoring. They found that in the neonatal population there was a strong correlation between the three but ETCO_2 underestimated PaCO_2 at a clinically unacceptable level (mean = 1.1 kPa). They recommended that transcutaneous CO_2 monitoring should be the preferred method during transportation.³⁴

Yosefy et al.³⁶ assessed the correlation of side stream ETCO_2 and PaCO_2 in the emergency centre for the non-intubated patient with respiratory distress. They found a strong correlation between the two and identified two variables, age and temperature, that influence this correlation. Respiratory rate, blood pressure, pulse rate and medical diagnosis had no significant effect on the correlation.³⁶ Evidence suggests that although capnography can be used, in most populations, PaCO_2 and transcutaneous CO_2 monitoring may be more accurate.

Portability of the ETCO₂ devices is extremely important in the out-of-hospital setting. A prospective study on healthy participants compared a small capnometre (EMMA™) with a reference standard capnometre. The authors found that the median difference between the EMMA™ and the reference standard was -0.3kPa (IQR -0.6 – 0.0; p=0.04). The difference was small and the authors concluded that it would be of limited clinical importance.³⁷

From the evidence reviewed it has been shown that capnography can be used to monitor respiratory function, allowing the user to identify early depression in respiratory rate or depth and to correct it before a hypoxic state develops. Where capnography is available, the practitioner may be able to identify ventilation issues faster than conventional means such as SPO₂ or auscultation would allow. There is however the concern of the correlation between PaCO₂ and ETCO₂. Finally with the availability of portable monitors it is easy to use capnography in the out-of-hospital setting to achieve the same goals as in-hospital practice.

4) Other uses of capnography identified in the literature review.

Using capnography as a diagnostic tool was mentioned in various contexts in the literature. There has been investigation into the role of in-hospital capnography in the diagnosis of sepsis,³⁸ the relationship with HCO₃,³⁹ the combined predictive value of NT-proBNP and ETCO₂ for acute heart failure,⁴⁰ and the predictive value of ETCO₂ for blunt trauma mortality.⁴¹

An important goal of sepsis resuscitation is achieving a central venous oxygen saturation (SCVO₂) of at least 70%. The monitoring of SCVO₂ is difficult in the emergency centre and the development of a correlate to this would be beneficial. A study by Guirgis et al.³⁸ found that there was no trend towards a significant relationship between ETCO₂ and SCVO₂. They did however establish a significant relationship between ETCO₂ and lactate. The authors concluded ETCO₂ may be beneficial in the quick triage of septic patients.³⁸

Kartal et al.³⁹ explored the possible relation between ETCO₂ and HCO₃. During their prospective study on spontaneously breathing patients they found a significant correlation such that an ETCO₂ level of 37mmHg or greater ruled out HCO₃ levels lower than 21mmol/L. As a triage tool ETCO₂ may be helpful in identifying the patient with significant metabolic disturbance.³⁹

In 2009, Klemen et al.⁴² examined the addition of capnography with NT-proBNP to differentiate causes of acute dyspnoea (i.e. acute heart failure from pulmonary disease). They found that in the 546 patients treated by emergency personnel, a NT-proBNP greater

than 2000 pg/ml and an ETCO₂ value of less than 4 kPa were strong predictors for acute heart failure.

Gilhotra and Porter,⁴⁰ looked at a cohort of patients between the ages of one and 18 years, presenting to an emergency centre. They established that none of the paediatric patients with an ETCO₂ less than 30 mmHg had diabetic ketoacidosis (DKA). They concluded that nasal capnography in conjunction with clinical assessment enables prediction of DKA. The ease of performing ETCO₂ makes this a viable screening tool for DKA.⁴⁰

A retrospective study looking at the mortality after blunt trauma established that ETCO₂ is a predictor of survival. ETCO₂ was measured 20 minutes after intubation. Median ETCO₂ of survivors was 4.1 kPa and 3.5 kPa in non-survivors (statistical significant - $p < 0.0001$). Only 5% of patients with an ETCO₂ of 3.25 kPa survived to discharged.⁴¹

Although, ETCO₂ cannot be used in isolation to make diagnosis in isolation, the ease of use and application of ETCO₂ makes it a valuable aid for use in the out-of-hospital environment.

Gaps identified in the literature review

Current use of ETCO₂ were identified and described, but it was found that there is limited low quality evidence for the use of capnography in the monitoring of cardiopulmonary resuscitation. South African evidence (and that from middle and lower income countries) was limited to two small studies from single sites which did not specifically answer any of the study objectives.

Conclusion

The use of capnography is increasing outside the operating theatre with many institutions and policy makers advocating it's use for multiple different indications. This literature review interrogated the Medline database for evidence regarding the knowledge of out-of-hospital practitioners regarding waveform capnography. Although this search yielded no results, a search in Medline for any published evidence related to capnography and the uses thereof in the out-of-hospital environment produced several useful studies. And a local search was done for unpublished work, which yielded two university degree dissertations from Johannesburg South Africa.

Several studies in the last 15 years have shown diverse uses for capnography in the emergency setting. The summary of the evidence was not specific to population group or

location where capnography where used, but on the applicability of the tool to the out-of-hospital environment.

The use of capnography for the confirmation of tube placement has been well described in the literature. The high sensitivity and specificity of the tool combined with portability makes it ideal for use in the out-of-hospital scenario, yet despite this (and increasing availability of the tool) there seems to be low utilization of the tool.

Capnography has been used during cardiac pulmonary resuscitation. The tool has specifically shown benefit when used to determine the quality of compressions or for the detection of return of spontaneous circulation.

Capnography is used for the monitoring of ventilation, and evidence suggests that it provides significant advantages for monitoring patients for respiratory depression, while there is conflicting evidence surrounding the agreement between ETCO_2 and PaCO_2 . Other uses for the tool were also described in the literature review.

In summary, there were a fair number of good evidence studies to advocate that capnography should be used as a monitoring tool in the out-of-hospital environment as currently recommended by international guidelines. Further studies should be done to identify and address the barriers that might exist in the out-of-hospital setting, specifically in low to middle income countries.

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Addendum A

Evidence is listed in decreasing level of evidence, newest evidence cited first.

Reference	Method	Primary outcome	Findings	Limitations
Li ⁸ (2001)	Meta-analysis	Appropriateness of ETCO ₂ for confirming ETT.	The study recommended that multiple methods of ETT confirmation be used as there are still rates of error on ETCO ₂ . <ul style="list-style-type: none">• The study reported false negatives of 7% and False positives of 3%.	No differences between colorimetric and capnography were discussed.
Langhan et al. ⁹ (2011)	Randomised Controlled Trial	Recognition of endotracheal tube dislodgement by paramedics. The study randomised paramedics and paramedic students as to the availability of capnography and the time to recognition of dislodgement.	The addition of capnography to standard monitoring improves time to correction of dislodgement of ETT by prehospital providers. <ul style="list-style-type: none">• Time between standard and capnography recognition was significant. (p=0.05)	The simulated environment was mentioned as a limitation, due to the reduction in external parameters.

Deitch et al. ¹⁰ (2010)	Randomised Controlled Trial	<p>Is the use of capnography associated with a decrease incidence of hypoxic events in the emergency centre? Randomisation occurred where physician had access to capnography and where they did not.</p> <p>End points were</p> <ul style="list-style-type: none"> • SPO2 less than 93% • ETCO₂ greater than 50mmHg • ETCO₂ change from baseline of more than 10mmHg or the loss of waveform. 	<p>The addition of capnography decrease reduced hypoxia and acted as an early warning system.</p> <ul style="list-style-type: none"> • Capnography identified all hypoxia cases before onset (Sensitivity 100%; Specificity 64%) 	<p>Lack of standardised validated definitions for hypoxia and respiratory depression (ETCO₂), could be a reason for the high rates of hypoxia identified in the study.</p> <p>Large number of participants were excluded due to lack of data captured.</p>
Deitch et al. ¹¹ (2008)	Randomised Controlled Trial	<p>The reduction of hypoxia during procedural sedation with Propofol. Patients were randomised to receive either supplemented oxygen or compressed air. End points were</p> <ul style="list-style-type: none"> • SPO2 less than 93% • ETCO₂ greater than 50mmHg • ETCO₂ change from baseline of more than 10mmHg or the loss of waveform. 	<p>No statistical significance could be established between the two groups.</p>	<p>Lack of standardised validated definitions for hypoxia and respiratory depression (ETCO₂), could be a reason for the high rates of hypoxia identified in the study.</p> <p>Research associates were not blinded, which could have introduced bias in the collection data.</p>

Deitch et al. ¹² (2007)	Randomised Controlled Trial	<p>The reduction of hypoxia (20%) during procedural sedation and analgesia using Midazolam and Fentanyl. Patients were randomised to receive either supplemented oxygen or compressed air. End points were</p> <ul style="list-style-type: none"> • SPO2 less than 93% • ETCO₂ greater than 50mmHg • ETCO₂ change from baseline of more than 10mmHg or the loss of waveform. 	<p>Supplemented oxygen did not reduce the incidence of hypoxia.</p> <ul style="list-style-type: none"> • Physicians failed to recognise respiratory depression in any patients that did not become hypoxic. 	The study was stopped early due to the amount of hypoxia identified would not have allowed for a 20% reduction, which was a primary outcome.
Helm et al. ¹³ (2003)	Randomised Controlled Trial	Determine the effect of out-of-hospital adjustment of ventilation based on ETCO ₂ , on PaCO ₂ .	Normo-ventilation was significantly higher in the group that received ETCO ₂ monitoring (P<0.0001)	<p>The study included only trauma cases.</p> <p>The inclusion of only physicians in the HEMS environment also makes it more limited to the study population.</p>

Zadel et al. ¹⁴ (2014)	Single-centred Prospective Study	<p>The aim of this study was to assess the sensitivity and specificity of POCUS for confirming proper tube placement.</p> <p>The authors assessed:</p> <ul style="list-style-type: none"> • Bilateral lung sliding • Diaphragm excursion <p>Results were measured against spectrographic quantitative capnography.</p>	<p>Results support POCUS as an accurate and reliable method for confirming the proper orotracheal tube placement.</p> <ul style="list-style-type: none"> • Three patients were identified with endobronchial tube placement. Capnography failed to detect the displacement in all three cases. 	<p>The sample size of oesophageal placement was low.</p> <p>Participants were from a single centre and not consecutively enrolled.</p>
Guirgis et al. ¹⁵ (2014)	Single-centred Prospective Study	<p>Determining the use of ETCO₂ as an end point of sepsis resuscitation.</p> <ul style="list-style-type: none"> • Determination of relationship between ETCO₂ and SCVO₂/Lactate 	<p>ETCO₂ is unlikely to be useful as an end point for sepsis resuscitation. It may be valuable as a triage tool.</p> <ul style="list-style-type: none"> • Relationship between ETCO₂ and SCVO₂ was not significant. (P=0.6) • Relationship between ETCO₂ and Lactate reported as significant (p=0.51) 	<p>The enrolment of patient only occurred during the daytime and not at night.</p> <p>The patient enrolled was all part of the invasive protocol, which is discourage at the institution and reserve for the sickest patients.</p>

Bowles et al. ¹⁶ (2011)	Multi-centre Prospective Study	Examination of all intubation that occur outside the operating theatre, collecting data on speciality and grade of intubator, presence of essential safety equipment and monitoring, and adverse events.	Essential safety equipment is often not available, despite existing guideline. This is associated with a high adverse event rate. <ul style="list-style-type: none"> • Capnography was not used in 32% of cases. • 39% of patients suffered adverse events. 	No blinding was done possibly introducing bias. Data was self-reported introducing bias around adverse events and availability of equipment. Recall bias is also a concern.
Kartal et al. ¹⁷ (2011)	Prospective cross-sectional study	Examine the relation between ETCO ₂ and HCO ₃ .	ETCO ₂ correlated moderately with HCO ₃ . The mean ETCO ₂ levels were statistically lower in patients who died.	Large number of patient excluded originally. No randomisation so concern regarding the introduction of confounding bias.

Botha ¹⁸ (2011)	Prospective Study	The study examined out-of-hospital missed intubations that arrived at an emergency centre	<p>2 missed intubation occurred during the study period. Neither of these were confirmed with ETCO₂.</p> <p>19% of the patients' ETTs were confirmed with ETCO₂ out-of-hospital.</p> <p>Only 4% of the medical practitioners used ETCO₂ as a confirmation device when the patient arrived at hospital.</p>	<p>Size of study.</p> <p>External validity as it was done in one province of South Africa.</p> <p>Reference standard, medical practitioners did not use gold standard or any set protocol to confirm tube placement.</p>
Cinar et al. ¹⁹ (2010)	Prospective study	Whether mainstream ETCO ₂ can accurately predict the PaCO ₂ level of patients with acute dyspnoea .	<p>Mainstream ETCO₂ can predict PaCO₂ in patients with acute dyspnoea.</p> <ul style="list-style-type: none"> • Strong correlation between ETCO₂ and PaCO₂ (P<0.001) • 80% of ETCO₂ measurement was between the range of ± 5 mmHg. 	<p>The authors question the disease severity of their patient as an important limitation for external validity.</p> <p>The PaCO₂ was not adjusted for temperature or respiratory rate.</p>

Hildebrandt et al. ²⁰ (2010)	Prospective Study	<p>Evaluation of a transportable capnometry (EMMA) or monitoring of ETCO₂. Reference standard was a capnometry.</p> <ul style="list-style-type: none"> Carbon dioxide values were recorded in various subjects. 	<p>The authors conclude that EMMA under-reads ETCO₂. But is comparable.</p> <ul style="list-style-type: none"> -0.3kPa IQR(-0.6 to 0.0) 	<p>There was time delay between the measurements of the tested sample and the reference sample, may influence the values.</p>
Delorme et al. ²¹ (2010)	Singled-centre Prospective Study	<p>Predicting capnia in the spontaneous breathing patients by ETCO₂.</p> <ul style="list-style-type: none"> Arterial blood gasses ETCO₂ 	<p>ETCO₂ does not seem to accurately predict PaCO₂ in patients with acute dyspnoea. Mean difference between ETCO₂ and PaCO₂</p>	<p>Small sample size (43) with several subgroups that made analysis of subgroups impossible. No mention of calibration or power of the sample size.</p>
Klemen et al. ²² (2009)	Prospective Study	<p>The accuracy of combination of quantitative capnography, NT-proBNP and clinical assessment.</p>	<p>The combination of ETCO₂, NT-proBNP and clinical assessment is superior then when compare to other groups without ETCO₂.</p>	<p>The severity of the patient recruited were not adequately assessed. Possibility of confounders on the results of ETCO₂.</p>

Jabre et al. ²³ (2009)	Prospective Study	<p>Assessment of the agreement between ETCO₂ and PaCO₂ in the non-intubated patient with respiratory distress.</p> <ul style="list-style-type: none"> Measuring differences between readings. 	<p>ETCO₂ measurements poorly reflect PaCO₂ values.</p> <ul style="list-style-type: none"> Mean difference of 12mmHg SD of the difference of 8mmHg 	<p>Only on PaCO₂ measurement was taken in contrast to continuous sampling of ETCO₂</p> <p>Small sample size made subgroup analysis impossible.</p>
Hinkelbein et al. ²⁴ (2008)	Prospective study	Analyse the accuracy and precision of ETCO ₂ , PaCO ₂ and transcutaneous CO ₂ monitoring in the ventilated adult patient during transportation.	PaCO ₂ and transcutaneous CO ₂ provide the best accuracy when compared with the reference standard.	Transcutaneous CO ₂ is not readily available in the prehospital environment and ambulances outside of Germany are not always staffed by specialist doctors, this questions the external validity of the study.
Gilhotra et al. ²⁵ (2007)	Prospective Study	<p>ETCO₂ as a screening tool to predict diabetic ketoacidosis in children with Type1 diabetes mellitus.</p> <ul style="list-style-type: none"> Sensitivity and specificity of ETCO₂ ability to predict presence of diabetic ketoacidosis. 	<p>Nasal capnography in conjunction with clinical assessment is predictive of DKA.</p> <ul style="list-style-type: none"> No patient with ETCO higher than 30mmHg had DKA Sensitivity 100%. Specificity 86% 	Low sample size of patients with DKA (15)

Belpomme et al. ²⁶ (2005)	Prospective Study	To determine the relationship between ETCO ₂ and PaCO ₂ in ventilation of the out-of-hospital patient.	Study determined that PaCO ₂ cannot be estimated by ETCO ₂ and that the variant becomes bigger over time.	The author mentions that the sample size was arbitrarily chosen. The end-point was not to determine the more applicable tool out-of-hospital.
Tingay, Stewart, Morley. ²⁷ (2005)	Prospective Study	Assessing the accuracy of ETCO ₂ measurement compared with PaCO ₂ and Transcutaneous CO ₂ in the neonatal population.	ETCO ₂ correlated strongly with PaCO ₂ and transcutaneous CO ₂ monitoring. The authors found a SD of 1.1mmHg between ETCO ₂ and PaCO ₂ and sited this as clinically unacceptable.	Small sample size.
Kober et al. ²⁸ (2004)	Prospective Study	The ease of use of capnography in the non-intubated patient during the transport time.	Capnography is easy to use. It was found that the % of malfunction of SPO ₂ was significantly higher than that of ETCO ₂ .	Study was done in Austria, which has a different population than Africa, and unknown and unexplained staffing model on ambulances.

Yosefy et al. ²⁹ (2004)	Prospective Study	Assess the accuracy of ETCO ₂ side stream to assess PaCO ₂ , and detect variable that might affect the correlation.	Study found a good correlation between PaCO ₂ and side stream ETCO ₂ . <ul style="list-style-type: none"> Age and body temperature was seen as independent variables. 	Small number of patients. (73) This study stated that different conditions or illnesses could have different variances.
Grmec, Mally (2004) ³⁰	Prospective study	To compare the three different methods of confirmation of ETT. <ul style="list-style-type: none"> Auscultation, Capnometry, Capnography 	Capnometry and Capnography had the same sensitivity and specificity (100%;100%) where auscultation had a sensitivity of 94% and specificity of 66%. (P<0.01)	Emergency physicians performed the intubation. Only patients with head injuries older than 18 was included, concerns for external validity.
Grmec, Klemen ³¹ (2001)	Prospective Study	Investigated the utility of ETCO ₂ as a prognostic tool for initial outcome of resuscitation. <ul style="list-style-type: none"> ETCO₂ was recorded initially, maximum level, minimum level and final level of ETCO₂ 	Sample 139 patients. Patient who survived had average ETCO ₂ of 18.8mmHg. Patient that could not be resuscitated had average ETCO ₂ of 7.1mmHg. Difference was statistically significant. 100% sensitive for ROSC if ETCO ₂ more than 10mmHg	Low sample size Did not report confounders, however did exclude certain patients. Not based on the same guidelines as present.

Hansen et al. ³² (2015)	Retrospective Study	To describe the characteristics of airway management, interventions, complication in the paediatric population in the United States.	CO2 confirmation techniques are not often used. <ul style="list-style-type: none"> • ETCO₂ used in 36.8% of intubations 	Self-reported data subject to bias. Large data base but only representative of certain services in the United States
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Bhat et al. ³³ (2014)	Retrospective Study	The impact of post-intubation intervention on mortality in patients boarding in the emergency centre.	Patient with 5 or more interventions had a decrease mortality when compared with 3 or less interventions. <ul style="list-style-type: none"> • 5.9% of patients received monitoring via ETCO₂ in the emergency centre. 	Retrospective analysis. Illness severity was different between the patients.
Heradstveit et al. ³⁴ (2011)	Retrospective Review.	Evaluating the factors complicating interpretation of capnography during OHCA.	Confounding factors in ETCO ₂ in cardiac arrest include; <ul style="list-style-type: none"> • Cause of cardiac arrest • Initial rhythm • Bystander CPR • Time until ETCO₂ applied 	Manual recording of ETCO ₂ in an already busy environment by the senior medical practitioner can introduce bias.

Pokorna et al. ³⁵ (2009)	Retrospective Review	Assessing the significant of the sudden increase in ETCO ₂ in determining the ROSC.	In constant ventilation ETCO ₂ is significantly higher after ROSC than before ROSC. (p=0.0001)	The study does not assess patient where they were unable to start ETCO ₂ before ROSC.
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Caulfield et al. ³⁶ (2009)	Retrospective Review	Do prehospital providers comply with the brain trauma foundation recommendation regarding hyperventilation during transportation of traumatic brain injuries?	There is 65% compliance to the brain trauma foundation recommendations.	The study also drew a conclusion regarding prehospital care and final outcome, however this was based on assessment after inhospital care. The study was small (100) with lots of exclusion of patients.
Deakin et al. ³⁷ (2004)	Retrospective Chart Review	Examine the records of patient with blunt trauma requiring prehospital ventilation to assess the relationship of ETCO ₂ to outcome	Only 5% of patient with a kPA of less than 3.25 at 20 minutes survived to discharge. The difference between survival and non-survival was statistical significant. (p<0.0001)	The study did not report limitations, but the study design is not strong to show correlation or association.
Shavit et al. ³⁸ (2010)	Web-based Questionnaire	Assessment of individual practice variation and to evaluate: <ul style="list-style-type: none"> The use of supplemental oxygen and capnography 	In the survey they identify that 45% of respondents did not use capnography.	Low respondent rate (10%). Survey study.

		<ul style="list-style-type: none"> Adverse events. 		
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Langhan, Chen ³⁹ (2008)	Web-based questionnaire	Evaluate current availability and utilisation patterns for ETCO ₂ in paediatric emergency centres.	<p>ETCO₂ is widely available but underutilised in the paediatric emergence centre.</p> <ul style="list-style-type: none"> Availability 88% for intubated and 53% for non-intubated. Only 20% used ETCO₂ always or often for sedation. Most common reason for not using ETCO₂ was due to lack of equipment. 	Limited by design. Sample was based in paediatric emergency medicine centres in the USA and Canada. Concern regarding the external validity.
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Delorio ⁴⁰ (2005)	Questionnaire	Determine the availability of ETCO ₂ for confirmation of ETT.	550 Surveys were assessed. 77% of facilities had colorimetric devices. 25% had continuous monitoring available. Among physician that had technology available 14% used it all the time.	External validity was named as a concern. Study design.
Graham et al. ⁴¹ (2003)	Questionnaire	Determining the type and range of equipment used in airway management in Scotland, emergency centres.	All centres had capnography available for use. 33% of them did not use capnography routinely to confirm ETT placement.	Small sample size (24). Study design.
Wood ⁴² (2004)	Questionnaire	The availability and use of capnography in emergency care in the Western Cape.	Tertiary and private hospitals had a 75% availability but was only 50% of doctors knew where it was stored. Very few doctors, nurses and paramedics thought that capnography was the best way to confirm ETT placement	Study design, External validity. Sample size was small.

Section C

Research presented in journal article format

Waveform capnography in the South African prehospital setting: Knowledge assessment of paramedics.

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Statement of Contributorship

CW conceived the study, collected & analysed the data, drafted & approved the final manuscript.

TW analysed the data & approved the manuscript

PH analysed the data & approved the manuscript

Word Count: 3091

Abstract

Background

Waveform capnography has proven to be of great value in the provision of safe patient care especially in the intubated patient. Capnography is now used in many prehospital services for confirmation of intubation, and optimization of resuscitation and ventilation. To date there has been little research into the knowledge of prehospital staff, both local and internationally, utilising capnography.

Aim

To describe the knowledge of paramedics who use waveform capnography in an out-of-hospital environment.

Methods

A cohort of advanced life support qualified paramedics in a private ambulance service in South Africa undertook a web-based survey around their background, training and use of capnography. Participants' knowledge was assessed by exploring their interpretation of waveform capnography and establishing attitudes pertaining to training and constraints of availability of capnography.

Results

Seventy eight paramedics responded, and most indicated they were very likely to use capnography when the tool was available (91%). The majority of training in capnography had been during their primary qualification (85%) Most participants indicated that they would like further training (91%). Use of capnography for confirmation of tube placement and quality of compressions during cardiopulmonary resuscitation was well understood (correct in 94% and 84% respectively), while more complicated knowledge such as waveform changes during ventilation (66%) and the effect of hypovolaemia (48%) on capnography were lacking.

Conclusion

Paramedics report using waveform capnography extensively when it is available in the South African out-of-hospital environment. Although the knowledge around capnography and its usage was found to be good in most areas, more complicated scenarios exposed flaws in the knowledge of many practitioners and suggest the need for improved and ongoing training.

Introduction

Capnography, also known as end-tidal carbon dioxide (ETCO₂) monitoring, developed in the late 1950s, and has become an essential tool for the provision of emergency care.^{1 2} Waveform capnography is a visual representation, depicted in a graph, of expired carbon dioxide (CO₂) that is generated as a metabolic by-product dissolved in blood until it diffuses into the alveoli.³

Since 2010, and with added impetus in 2015, the guidelines of the International Liaison Committee on Resuscitation (ILCOR)⁴ advocate the use of waveform capnography for confirmation and continuous monitoring of endotracheal tube (ETT) placement. Capnography has also proven to be of value in monitoring physiological processes including the effectiveness of cardiac compressions, return (or loss) of spontaneous circulation, ventilation, and haemodynamic status.⁵

In South Africa, emergency medical services (EMS) are divided into two sectors, private and public. The public EMS services are operated by provincial government and mandated to provide care to the general public, charged according to means, thus generally serving the lower socio-economic sector.⁶ The private EMS industry general serves the insured population who are largely part of the middle- and high-income earners or who have access to alternative reimbursement methods, such as the Road Accident Fund, Workmen's Compensation or private contracts. In South Africa there are in excess of 250 private ambulance services, with less than ten of these having a national footprint.⁷

South African EMS has three broad levels of practice, namely basic, intermediate, and advanced. These do not differ between public or private industry. Providers can achieve advanced life support (ALS) qualification (these are the practitioners who are able to intubate and ventilate patients, and the usage of capnography is within their scope and training) via two different routes. The first route is qualification via a series of short courses which allow in-service progression, ultimately with a one year course graduating candidates as Critical Care Assistants (CCA). The second route is via tertiary qualification from a university which qualifies practitioners with a national diploma (N.Dip) after three years (now largely discontinued) or a bachelor of emergency medical care (B.Tech/B.EMC) after 4 years. The scope of practice is regulated by the Health Professions Council of South Africa. The qualifications CCA, N.Dip, B.Tech and B.EMC in the South African setting all equate to Advanced Life Support Paramedics, which shall for the purposes of this research be referred

to as paramedics. Capnography forms part of the scope of practice of advanced life support providers.

Previous studies in South Africa have examined the use, knowledge and availability of capnography in emergency centres.^{8 9} The current study was undertaken to establish the knowledge and utilization of waveform capnography of a cohort of paramedics in their clinical practice.

Methods

Paramedics in South Africa with access to capnography from a single private ambulance service were invited to complete a web-based survey that was generated from a structured literature review, piloted and then distributed to a cohort of practitioners, known to all have access to capnography. The service, one of the largest in the country, operates in 8 of the 9 provinces of South Africa, and manages 280 ambulances and rapid response vehicles, responding to an excess of 260 000 emergency calls a year.⁷ In 2015 the paramedics employed by the service treated 1177 patients who were either intubated or ventilated.⁷ It has an institutional policy requiring practitioners to use capnography on all intubated patients.

A survey was designed to gather the demographics of participants, as well as to depict their background, training, and willingness to use the tool. The participant's knowledge was assessed using a series of short questions, specifically exploring their interpretation of waveform capnography by presenting a series of case examples to be identified. Open ended questions were used to establish the respondents' attitudes pertaining to training and constraints of availability of ETCO₂.

A pilot study of five senior practitioners in the prehospital industry established face validity. Based on employment records, there were 112 ALS providers employed in the service, and with an anticipated response rate of at least 60% this would provide adequate data for analysis.¹⁰ Inclusion criteria were permanent employment with the private ambulance service and registration with the Health Professions Council of South Africa as a paramedic or emergency care practitioner.

Participants were sent an email containing a link to the survey. After consenting, participants were enrolled into the study. Participants who had not started or fully completed the survey were sent three weekly reminders. Data were collected using a web-based form (Survey Monkey®, www.surveymonkey.net). Data were presented as numbers, means, medians and

standard deviations as appropriate using IBM SPSS® Statistics Version 22 software. Free text comments underwent analysis by thematic coding and analysis using basic qualitative techniques.

Ethics approval for the research was obtained from the University of Cape Town's Faculty of Health Sciences' Human Research Ethics Committee (HREC REF: 681/2015). Permission was granted by the research committee of the participating ambulance service, and each individual participant consented at the start of the questionnaire.

Results

One hundred and twelve surveys were distributed and 80 responses were returned between October 2015 and November 2015, yielding a response rate of 80/112 (71%). There were 58 complete responses and 22 were partially completed. Of these 22 partially completed surveys, five participants exited the survey during the knowledge based questions, a further eight during the scenario based waveform questions, and seven in the open-ended questions. Two respondents were excluded from the analysis (one did not grant consent, the other completed demographic information only), giving a total of 78 included responses (incomplete surveys were included for those questions answered).

The majority of respondents were male 54/78 (69%), with a median age of 34 years and an interquartile range (IQR) of 27 to 38 years. Responses were received from all provinces where the service operates. Characteristics of the respondents are summarised in Table 1.

Participant training and reported usages of capnography

Sixty seven (85%) paramedics indicated they were taught how to utilise capnography during their primary qualification, while 32/78 (41%) indicated that they received training subsequently during a 2-day professional course. Participants had undergone training a median of three years (IQR 2-6 years) prior to the survey.

Nearly all participants 53/58 (91%) indicated that they would like further training in the use of ETCO₂, with 18 of the 58 respondents indicating that they considered themselves out of date or that their initial training was not sufficient with respect to capnography. When asked how training should be delivered the following key words were identified in the analysis: continuous medical education (14), online training (9), lectures (12), workshops (7), and practical training (6).

Of the 78 respondents, 61 reported that they do use capnography for more than 90% of their patients when the tool is available. In the CCA cohort only 26/38 (68%) of participants reported more than 90% use, whereas 35/40 (80%) of respondents with a tertiary qualification (NDip and Btech/BEMC) reported more than 90% use. (Table 2) Capnography was identified as a necessity in the day-to-day practice by 74/78 (94%) of these respondents.

Knowledge about the usage of capnography and interpretation of waveforms

(Figure 1 – Shows the percentage who correctly answered the waveform capnography interpretations)

Intubation

Almost all the respondents 70/74, (94%) indicated that ETCO₂ can aid in the identification of ETT placement, while a small number (4) indicated that it can only assist in some circumstances. When asked to identify a waveform indicating apnoea, 50/66 (75%) could identify that the lack of waveform on a ventilated patient indicated apnoea. Forty-eight of the 66 (71%) of the respondents were able to identify a curare cleft as a sign of return of spontaneous breathing after the administration of a paralytic.

Monitoring during CPR

The majority, 61/74 (82%), indicated that ETCO₂ can be used to monitor the quality of compressions during CPR, whilst only 51/73 (69%) of participants said that ETCO₂ could be used to predict the return of spontaneous circulation. Yet from the scenario waveforms, only 41/69 (59%) could identify a waveform indicating adequate compressions during CPR, and 43/69 (62%) identified the waveform scenario as showing inadequate CPR. The return of spontaneous circulation was correctly identified by 55/69 (79%) of respondents.

Optimizing Ventilation

Almost all of the participants 73/74 (98%) stated that capnography could assist in optimizing ventilator settings. Yet only 45/68 (66%) correctly identified a waveform indicating hyperventilation, and 11/68 (16%) incorrectly identified the same graph as hypoventilation. Some 46/68 (67%) of respondents correctly identified that in order to increase the ETCO₂

reading, the minute volume had to be decreased. When asked whether the ETCO₂ has an effect on oxygen saturation 26/73 (35%) answered yes and 17/73 (23%) of the participants reported that an increase in fractional inspired oxygen would decrease the ETCO₂. The identification of changes in the waveform from normal to bronchospasm was correctly identified by 38/68 (55%), with 13/68 (19%) unable to identify what the curve illustrated.

Other Uses of Capnography

In a polytrauma scenario 32/66 (48%) of respondents correctly identified the need for fluid replacement when hypocapnia was not improving with ventilation adjustments, while 14/66 (21%) interpreted the graph as indicating a needing to check the ETT for correct placement. And 50/66 (75%) of the respondents correctly identified the graph illustrating apnoea or tube displacement.

Resource constraints and availability

Respondents were asked why they might not use capnography, to which the majority 51/66 (77%) said that they always use ETCO₂. However 25/66 (37%) indicated that there is a concern regarding the availability of the consumables. Two practitioners noted that if the transport time to hospital is short then the respondents would not use CO₂ monitoring. Most respondents indicated that there are no concerns with accessibility to the technology, with one respondent commenting, *“waveform capnography is always available at the base I work”*.

Clinical use

Almost all of the respondents 59/60 (98%) reported that ETCO₂ does make a difference in their clinical practice when used. Most of the comments made, specifically related to the control of ventilation when using ETCO₂ indicated that the use of ETCO₂ should be mandatory practice within the ambulance service. One of the respondents commented saying, *“I believe it should be mandatory as it can instantaneously pick up any adverse issues with the ventilation in real time which helps in the back of a moving ambulance.”*

Discussion

The use of waveform capnography has been established to be of benefit both for patient safety and the augmentation of treatment modalities.¹¹ While EMS can procure and deploy new technology, the implementation of this technology is often reliant on several factors, including the limited insight into benefits of a technology, and the required expertise and know-how in applying the technology.¹² In 2011, having conducted a local multi-sectorial study, Botha⁹ found that only 19% of South African paramedics used ETCO₂ for the verification of tube placement in the out-of-hospital setting. In stark contrast, we demonstrated a large proportion (90%) of paramedics that utilise capnography in the out-of-hospital environment in 2015. It is likely that this is mainly due to increased availability over the next 4 years.⁹ Botha, study did include a cohort from both private and public services were the current study specifically investigated one private service. The service studied here, gradually procured capnography from 2011 onwards. The availability of consumables may however have further impact adoption and use of capnography within the service.

Continuous waveform capnography is the most reliable way to establish ETT placement.¹³ We found that paramedics correctly identified the indication for ETT verification, but only three quarters could identify apnoea. During intubation training it is often emphasized that capnography can be used for the verification of ETT placement, yet practitioners would seem to be less familiar with the continuous application of the rule.

ETCO₂ has been established to be of value in monitoring the quality of compressions during cardiopulmonary resuscitation and is recommended as standard practice,⁴ which was known by the majority of this cohort. A consensus statement released in *Circulation* in 2013¹⁴ indicates that an ETCO₂ of less than 10 mmHg during CPR, when adequate CPR is being performed, is a strong predictor for unsuccessful resuscitation. A subsequent systematic review concluded that although ETCO₂ values do correlate with ROSC the cut-off of the predictive values is not fully established.¹⁵ In this study only two thirds indicated that ETCO₂ could be used as a predictor for ROSC. Although current resuscitation training highlights the quality of CPR ("Push Hard, Push Fast"⁴), the predictive value of ETCO₂ may not be emphasized in training, and would seem to be poorly understood by the paramedic.

Capnography is an immediate feedback tool with regards to ventilation and can be used to adjust ventilation when other modalities like arterial blood gas analysis are not available.¹⁶ Only two thirds of the participants were able to identify hyperventilation and how to correct it. Literature regarding the ability of paramedics to adjust ventilation based on ETCO₂ is limited. Davis et al.¹⁷ found that hyperventilation occurred often following paramedic rapid sequence intubation, despite the use of ETCO₂. A recent unpublished university thesis¹⁸ which

surveyed 20 South African paramedics, reported that as many as 80% of paramedics could identify hyperventilation. Small numbers and the limited geographical setting may affect the external validity of this study.¹⁸ The findings of our study are thus in keeping with prior studies, although a significant number of participants did however indicate that FiO₂ and oxygen saturation had influence on ETCO₂, suggesting room for improvement in the knowledge and use of ETCO₂ during ventilation.

A large number of the participants indicated that they would like further training in the use of waveform capnography. It is difficult to establish the exact content of training received by paramedics during their primary qualification as the curricula vary between institutions. Knox et al.¹⁹ established that Irish paramedics prefer practical type learning. This was in keeping with the findings of this study where most participants indicated that they would like training in workshops or practical simulations. Less than half of the participants indicated that they have received ongoing training related to the use of waveform capnography during widely accepted advanced life support short courses or continuous medical education. The impact of such training programs is unclear, and regular updates and refreshers are recommended to maintain competency.²⁰

An improvement project conducted by a private service helicopter emergency medical service showed that online learning platforms can be implemented in South Africa, and this could be a cost effective way of achieving further training.²¹ In the out-of-hospital setting further training in waveform capnography needs to take all aspects of improvement and change methodology into consideration, understanding what is needed and monitoring outcomes to narrow the identified knowledge gaps.

Limitations

The study was conducted in a single private emergency medical service, raising the concern of applicability or external validity of these results to all paramedics in South Africa. Capnography is theoretically available in all vehicles in this private service, whilst other services and the public sector have variable but often minimal access to capnography. We believe this cohort provides a useful assessment of early implementation which can guide this service in optimizing use, as well as guiding further nationwide roll-out and use of capnography.

The principal investigator is a senior employee of the private ambulance service. Although the respondents are not directly subordinate, this may have influenced how the questionnaire was answered, and possibly the willingness to take part in the questionnaire. The company subscribes to a 'just' culture, meaning that a non-punitive approach is employed whenever staff report events, and for this reason and anonymity we feel that participants would have felt free to answer the survey honestly.

Inherent survey limitations apply including: recall bias, self-reporting bias and non-response bias. The study was anonymous, only relating to practitioners currently using capnography and three reminders were sent to improve response rates. Causation cannot be established as the study is descriptive in nature. Further research would have to be conducted to establish the interpretation of the knowledge base that has been described by this study.

Conclusion

Capnography is a valued tool in the out-of-hospital setting where the tool is available. We have established that in a setting where the tool is readily available, most practitioners report that they will choose to make use of the ETCO₂ monitoring. The capabilities of ETCO₂ seem to be well understood, however the ability to interpret different waveform capnographs is variable. The study identified that there is a need for further education of paramedics in the interpretation of waveform capnography.

What this paper adds box

What is known?

- In the South African setting capnography is being used by many paramedics when available.
- It is uncertain what the knowledge of paramedics is around the use and interpretation of waveform capnography.

What this paper adds?

- An understanding of the knowledge of advanced life support paramedics on waveform capnography.
- Training needs within the population of paramedics.

Table 1 - Characteristics of Participants

Table 1: Characteristics of Participants		
Age (Years) Group	Median = 34 (IQR* 27-38)	
	Number	Percentages
20-29	28	35%
30-39	37	47%
40-49	11	14%
50-59	2	2%
Gender		
Male	53	67%
Female	25	32%
Operational Division		
Aeromedical Operations	6	7%
ICU** transfer operations	4	5%
Road Operations	68	87%
o *IQR: Inter-quartile range **ICU: Intensive Care Unit		

Table 2 - Qualification, training and usage of capnography

Table 2: Qualification, training and usage of capnography			
	Tertiary Qualification (40)	CCA (38)	Total (78)
Usage of Capnography	n (%)	n (%)	n (%)
Every patient >90%	35 (87%)	26 (68%)	61 (78%)
Mostly 60%-90%	2 (5%)	10 (26%)	12 (15%)
Usually 50%	3 (8%)	-	3 (3%)
Never 10%	-	2 (5%)	2 (2%)
Training in capnography received			
Primary Qualification	36 (87%)	31 (81%)	67 (84%)
Advanced Life Support Short Courses	10 (24%)	22 (57%)	32 (40%)
In-service training	9 (22%)	10 (26%)	19 (24%)

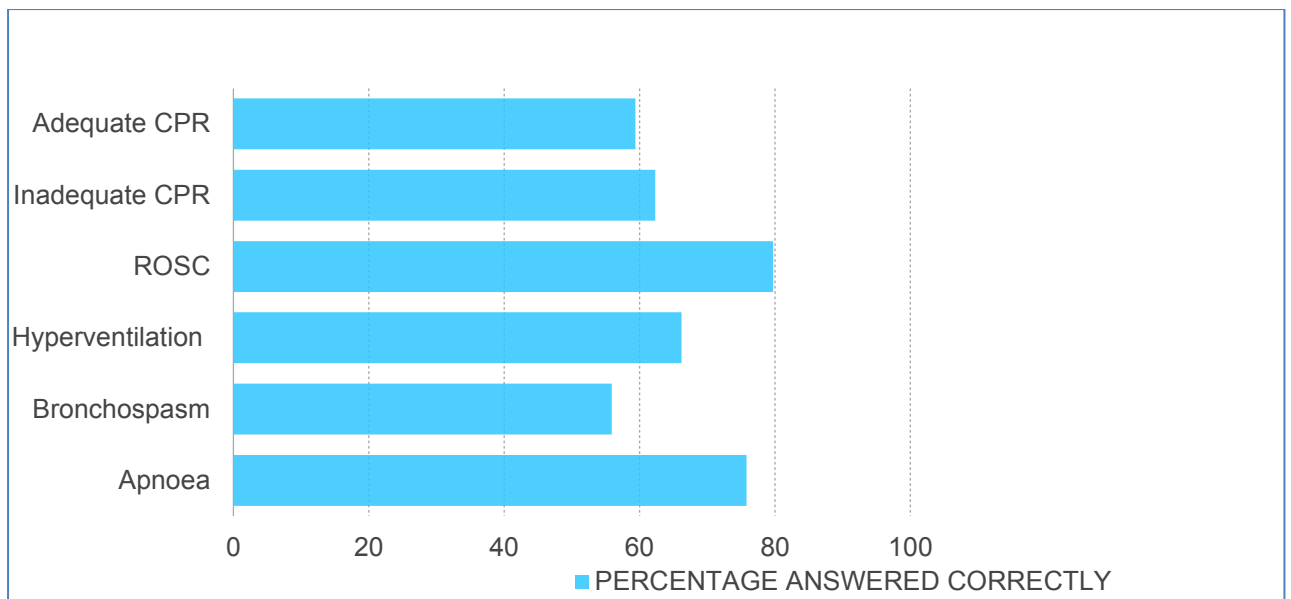


Figure 1 - Percentage who correctly answered the waveform capnography scenario

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Appendix 1 – Ethics Approval



UNIVERSITY OF CAPE TOWN
Faculty of Health Sciences
Human Research Ethics Committee



Room E52-24 Old Main Building
Groote Schuur Hospital
Observatory 7925
Telephone (021) 406 6338 • Facsimile (021) 406 6411
Email: ncsi.tsama@uct.ac.za
Website: www.health.uct.ac.za/fhs/research/humanethics/forms

17 September 2015

HREC REF: 681/2015

Dr T Welzel
Surgery
Emergency Medicine
J45.56
Old Main Building

Dear Dr Welzel

PROJECT TITLE: WAVEFORM CAPNOGRAPHY IN THE SOUTH AFRICAN PREHOSPITAL SETTING: KNOWLEDGE ASSESSMENT OF QUALIFIED ADVANCED LIFE SUPPORT (ALS) PARAMEDICS (MPhil candidate-C Wylie)

Thank you for submitting your study to the Faculty of Health Sciences Human Research Ethics Committee for review.

It is a pleasure to inform you that the HREC has **formally approved** the above-mentioned study.

Approval is granted for one year until the 30th September 2016.

Please submit a progress form, using the standardised Annual Report Form if the study continues beyond the approval period. Please submit a Standard Closure form if the study is completed within the approval period.

(Forms can be found on our website: www.health.uct.ac.za/fhs/research/humanethics/forms)

We acknowledge that the student, Craig Wylie will be involved in this study.

Please quote the HREC REF in all your correspondence.

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Yours sincerely

Signature removed

PROFESSOR M BLOCKMAN
CHAIRPERSON, FHS HUMAN RESEARCH ETHICS COMMITTEE

Federal Wide Assurance Number: FWA00001637.

Institutional Review Board (IRB) number: IRB00001938

This serves to confirm that the University of Cape Town Human Research Ethics Committee complies to the Ethics Standards for Clinical Research with a new drug in patients, based on the Medical

HREC 681/2015

Cambridge Manor Office Park, Manor 1, Cnr Stone Haven and Witkoppen Roads, Paulshof, Sandton, South Africa, 2058
PO Box 242, Paulshof, Sandton, South Africa, 2058
Tel: Local: 0861 084 124 • International: + 27 (0) 11 3196300 • Email: info@er24.co.za • www.er24.co.za
Ethics Line: 0800-005-316

08 October 2015

Craig Wylie
Department of Emergency Medicine
University of Cape Town

Dear Mr Wylie,

RE: PROJECT 2015/06
PROJECT TITLE: Waveform capnography in the South African prehospital setting: Knowledge assessment of qualified advanced life support (ALS) paramedics.

The above research protocol has been reviewed by the ER24 Research Committee and I am pleased to inform you that your request has been approved. Access is hereby granted to the data required as stipulated in your protocol.

Should your methodology change or any concerns arise during the data collection period, it is your responsibility to inform the ER24 Research Committee in due course. You are also required to forward the completed project to ER24.

I look forward to viewing the results of your study. I am positive that the science that you will generate will be of benefit to the profession.

Kind Regards,

Signature removed

Dr Robyn Holgate
ER24 Research Committee
Chief Medical Officer

ER24 is a 100% subsidiary of Mediclinic Southern Africa
ER24 EMS (PTY) LTD t/a ER24
Registration No. 2000/005657/07 • VAT Registration No. 4730193887

realhelprealfast

Appendix 2 – Emergency Medical Journal author guidelines

Author guidelines were accessed on the internet on 11 March 2015. The guidelines were copied and presented here in the original format, without being formatted: (<http://emj.bmj.com/site/about/guidelines.xhtml>)

Original Articles

Full length articles reporting research. Authors of original articles are required to comply with one of the appropriate reporting guidelines endorsed by the [EQUATOR Network](#). More information can be found [here](#).

Checklist Choices

BMJ requires compliance with the following reporting guidelines; please upload your completed checklist with your submission and label it "Research Checklist". Below is a list of the most commonly used research checklists which should be selected based on the type of study you are reporting. If your study's methodology does not have a suitable research checklist you may submit the paper, but must state in the cover letter why no checklist is attached.

CONSORT statement - Required for all randomised controlled trials

PRISMA statement - Required for all systematic reviews

EVEREST statement - Required for all economic evaluations

STARD statement - Required for all diagnostic research papers

STROBE statement - Required for all observational studies

MOOSE statement - Required for all meta-analyses of observational studies

Guidance and forms are available [here](#).

Abstract: 250 words

Word count: up to 3000 words

Illustrations and tables: up to 6

References: 25

Additional information (such as data collection tools, surveys, etc) may be placed on the web site as a data supplement. In some cases, we may ask to publish the abstract in print and the full-length article on the website only.

You also have the option to publish the abstract of your paper in your local language. If you wish to do this, please upload a Word copy of your abstract to your manuscript on Scholar One and save it as 'supplementary material'.

We have specific requirements for before and after (pre-post) studies. Please see Goodacre, March 2015 ['Uncontrolled before-after studies: discouraged by Cochrane and the EMJ'](#).

Recommended Sections:

Introduction: The article should include a brief introduction explaining why you chose to do the study – this would include a description of the importance of the topic, a summary of what is already known and why the study was needed, and the goal of the study. Three to four paragraphs should be sufficient.

Methods: Guidelines exist for the reporting of methodology and results for randomized trials, observational studies and retrospective chart review. Please see above or refer to the [EQUATOR website](#) for guidelines according to the specific type of study. The Methodology section must include a statement about ethics approval before it can be reviewed. Clinical trials must be previously registered and the registration number given.

Results: Please follow the standardized guidelines (as in Methods) for reporting of results. For statistics, confidence intervals are preferred to p values.

Discussion: The discussion should begin with a brief summary of the findings (no more than one paragraph) followed by the following (in whatever order works best in the flow of the article): how this study is similar or different from prior studies with regards to methods and results; limitations of this study; implications of the results for practice or policy. If you wish to offer a conclusion, this should be done in the last paragraph of the Discussion rather than as a separate subsection.

Tables should be placed in the main text where they are first cited while figures should be provided as supplementary files.

"What this paper adds" Box

Please produce a box offering a thumbnail sketch of what your article adds to the literature, for readers who would like an overview without reading the whole article. It should be divided into two short sections, each with 1-3 short sentences.

Section 1: What is already known on this subject

In two or three single sentence bullet points please summarise the state of scientific knowledge on this subject before you did your study and why this study needed to be done. Be clear and specific, not vague.

For example you might say: “Numerous observational studies have suggested that tea drinking may be effective in treating depression, but until now evidence from randomised controlled trials has been lacking/the only randomised controlled trial to date was underpowered/was carried out in an unusual population/did not use internationally accepted outcome measures/used too low a dose of tea.”

Or: “Evidence from trials of tea therapy in depression have given conflicting results. Although Sjogren and Smith conducted a systematic review in 1995, a further 15 trials have been carried out since then...”

Section 2: What this study adds

In one or two single sentence bullet points give a simple answer to the question “What do we now know as a result of this study that we did not know before?” Be brief, succinct, specific, and accurate. For example: “Our study suggests that tea drinking has no overall benefit in depression”.

You might use the last sentence to summarise any implications for practice, research, policy, or public health. For example, your study might have: asked and answered a new question (one whose relevance has only recently become clear) contradicted a belief, dogma, or previous evidence provided a new perspective on something that is already known in general provided evidence of higher methodological quality for a message which is already known.

Appendix 3 – Data collection tool

Section A - Demographics

1. Age:____
2. Sex
 - o Male
 - o Female
3. Years of experience in the out-of-hospital environment where capnography is available?
 - o In Years
4. Current province of employment
 - o Western Cape
 - o Gauteng
 - o Eastern Cape
 - o Northern Cape
 - o Kwa-Zulu Natal
 - o Limpopo
 - o North West
 - o Mpumalanga
 - o Free State
5. Operational staff member in the employment of ER24 as an advanced life support paramedic
 - Yes
 - o No
6. Current Qualification
 - o CCA
 - o N.Dip
 - o B.Tech/B.EMC
7. Operational division you currently work primarily in:
 - o Road Operations
 - o Aeromedical Operations
 - o ICU transfer operations

8. Do you currently have end-tidal carbon dioxide (ETCO₂) available for more than 50% percent of your operational duties?

- Yes
- o No

Section B - Background

9. Have you received formal training in the interpretation of capnography?

Yes / No

(If answers No skip the next question)

10. Where did you receive this training?

- During your training for your primary qualification (NDip, BTech, CCA)
- Short course (ACLS, APLS, PALS, ATLS, ITLS etc..)
- In-service training
- CME
- Other: _____

11. Is ETCO₂/capnography a necessity in your day to day clinical practice and treatment of the intubated patient?

Yes / No

- Does your company have a policy regarding the use of ETCO₂/capnography in the intubated patient?

Yes/No/I don't know

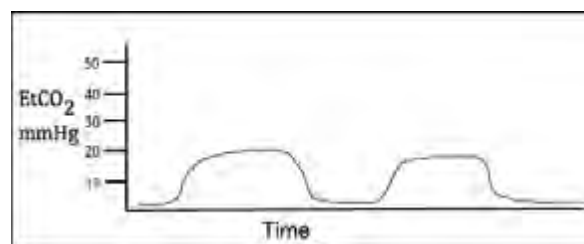
13. When available do you use ETCO₂ on every intubated patient?

Yes/No/Usually/sometimes

	YES	In some circumstances	No	Unsure
14. Can ETCO ₂ be used for the confirmation of endotracheal tube placement?				
15. Can ETCO ₂ be used for the adjustment of ventilation?				
16. Can ETCO ₂ be used for to monitor the quality of cardiopulmonary resuscitation?				
17. Can ETCO ₂ be used to accurately predict the probability of ROSC?				
17. Can ETCO ₂ predict the outcome of a patient in cardiac arrest?				
18. Is there any correlation between ETCO ₂ and serum Bicarbonate?				
19. Can ETCO ₂ be use on a non-intubated spontaneously breathing patient?				
20. Is ETCO ₂ a useful measure of the haemoglobin level of a ventilated patient?				
21. Is ETCO ₂ a true reflection of oxygenation in the intubated patient?				
22. Will increasing the FiO ₂ of an intubated patient, decrease the ETCO ₂				

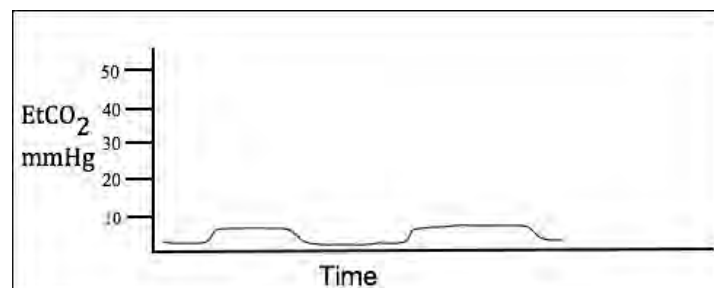
Section C - Scenarios

23. Cardiopulmonary resuscitation is being done on a pulseless patient following a suspected myocardial infarction. Before your arrival the patient received standard Advanced Life Support resuscitation as prescribed by the American Heart Association (AHA) including intubation. On your arrival you connect the capnograph. What can you conclude from the graph?



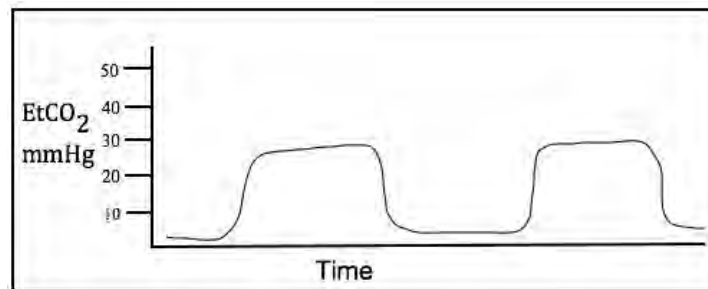
- Normal Capnography/Hypoventilation/Hyperventilation/Bronchospasm/Adequate CPR/Inadequate CPR/Return of Spontaneous Circulation/Apnoea/ Partial Tube occlusion / I don't know

24. After approximately 2 minutes you notice a change in the graph presented on your monitor. What can you conclude from the graph?



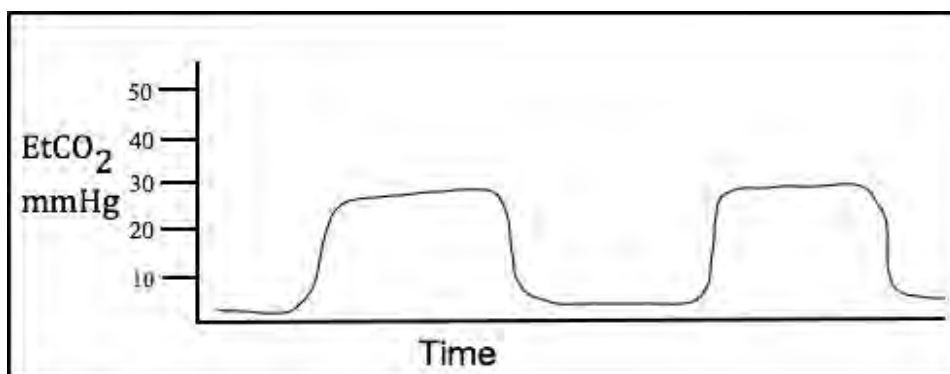
- Normal Capnography/Hypoventilation/Hyperventilation/Bronchospasm/Adequate CPR/Inadequate CPR/Return of Spontaneous Circulation/Apnoea/ Partial Tube occlusion / I don't know

25. The resuscitation continues for approximately 15 minutes, at which stage you notice an abrupt change in the capnography trace. What can you conclude from this graph?



- Normal Capnography/Hypoventilation/Hyperventilation/Bronchospasm/Adequate CPR/Inadequate CPR/Return of Spontaneous Circulation/Apnoea/ Partial Tube occlusion / I don't know

26. You plan to intubate a (different) patient that has a traumatic brain injury. You adequately pre oxygenate your patient for 3 minutes. The intubation is easy and the procedure is completed quickly. You immediately connect the capnography and see the following graph. What does the graph indicate?

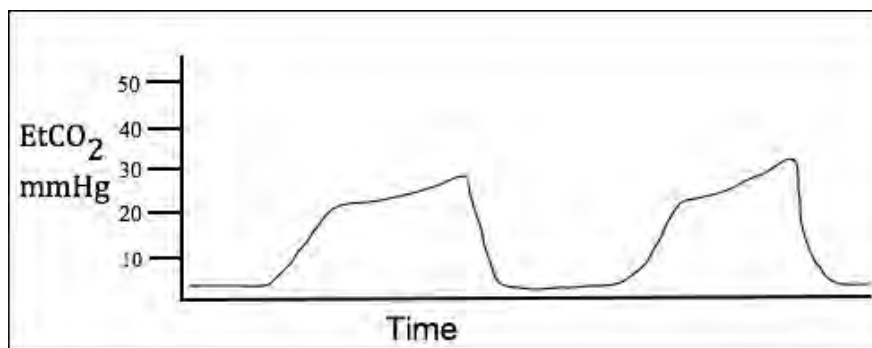


Normal Capnography/Hypoventilation/Hyperventilation/Bronchospasm/Adequate CPR/Inadequate CPR/Return of Spontaneous Circulation/Apnoea/ Partial Tube occlusion.

27. This patient's ETCO_2 reading is 28mmHg (3.7 Kpa). The patients' haemodynamic state is normal. Is any action necessary and if so what?

- Nil/ Assess for tube placement / Assess for bronchospasm / decrease minute volume / increase minute volume / correct chest compression / give volume replacement / I don't know

28. During your transportation of this patient, the following capnograph develops. What is the most likely cause?

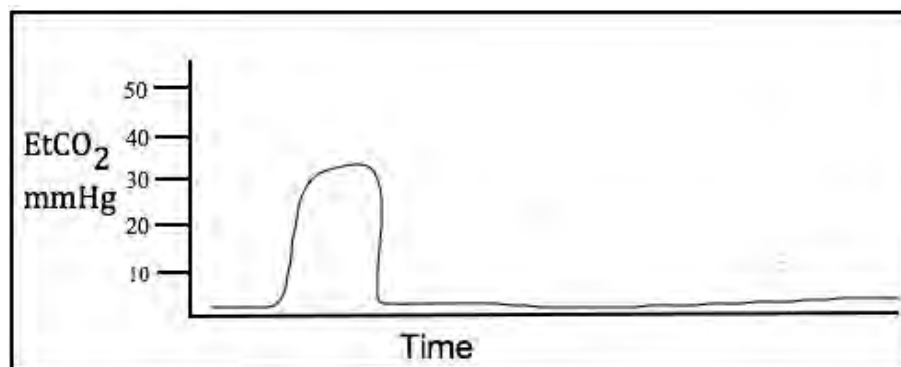


- Normal Capnography/Hypoventilation/Hyperventilation/Bronchospasm/Adequate CPR/Inadequate CPR/Apnoea/ Partial Tube occlusion / I don't know

29. You have just intubated a patient with a fractured pelvis and a distending abdomen. You started ventilation with lung protective strategies, and despite trying to manipulate the ventilation you are still unable to get the ETCO_2 above 28mmHg. What would be your action to correct this reading?

- Assess for tube placement / Assess for bronchospasm / decrease minute volume / increase minute volume / correct chest compression / give volume replacement / I don't know

30. During your transportation of a patient your capnograph suddenly change to the following tracing. What is the most likely reason?



- Normal / Capnography/Hypoventilation/Hyperventilation/Bronchospasm/Adequate CPR/Inadequate CPR/Apnoea/ Partial Tube occlusion / I don't know

Section D - Open Ended Question

31. If you have a capnograph available on your vehicle, what would be some reasons that would prevent you from using the tool? (Select one or more)

- ☐ I always use ETCO₂ on my intubated patients, when available
- ☐ Non-availability of consumables
- ☐ It is not important for all intubated patients.
- ☐ It delays scene time and due to this is not important.
- ☐ I don't find it helpful.
- ☐ I don't fully understand capnography, so I am not comfortable using it.
- ☐ Other:

32. Do you have any further comments regarding the topic of capnography? (please comment on any issues raised by this study, such as access to capnography, attitude of yourself and colleagues to capnography, benefits and improvement in patient care, difficulties in use/ interpretation, downside of capnography in your practice)

Appendix 4 – Consent form

TITLE OF THE RESEARCH PROJECT: Waveform capnography in the South African prehospital setting: Knowledge assessment of qualified advanced life support (ALS) paramedics.

PRINCIPAL INVESTIGATOR: Craig Wylie

SUPERVISORS: Peter Hodgkinson, Tyson Welzel

CONTACT DETAILS: 0788005644, craig.wylie@me.com

Dear Prehospital Care Provider

You are being invited to take part in a research project. Please take some time to read the information presented here, which will explain the details of this project. Please feel free to email me with any questions about any part of this project that you do not fully understand. It is very important that you are fully satisfied that you clearly understand what this research entails and how you could be involved. Also, your participation is **entirely voluntary** and you are free to decline to participate. If you say no, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point, even if you do agree to take part.

This study has been approved by the Health Research Ethics Committee at University of Cape Town and will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki, South African Guidelines for Good Clinical Practice and the Medical Research Council (MRC) Ethical Guidelines for Research.

What is this research study all about?

We are investigating prehospital advanced life support paramedics' ability to interpret and make decision based on waveform capnography.

Why have you been invited to participate?

If you are a Prehospital Care Provider registered with the Health Professionals Council South Africa (HPCSA) as either a paramedic or emergency care practitioner currently in employed at ER24 as operational staff in clinical care then you are eligible to participate.

How will this research project be conducted?

This research project requires you to complete a demographic survey and answer a series of short questions. Information will be collected anonymously – the survey and test are in no way linked to your personal details. If completion of the survey is interrupted due to operational emergency call-out, it can be completed at a later stage.

What is your responsibility if you choose to participate in this research project?

All that is required for participation is your time for completion of the survey as outlined above. Your participation is completely voluntary and you are free to decline to participate. You will not be paid to participate in this research project, and there will be no costs involved for you. You are free to withdraw from the study at any point, even if you do agree to take part, without penalty. Benefits of this research project, although not directly applicable to you at this stage, will hopefully be seen in an improved teaching and guidelines regarding management of intubate and ventilated patients.

Written consent is required as part of this study design: if you consent to participate in the study, select the "I do consent" below, by doing so it is assumed that you have connected and is happy taking part in the survey. If you do not consent to be involved in the study, select the "I do NOT consent", no further action is required.

- **You can contact Craig Wylie on 0788005644 or craig.wylie@me.com if you have any further queries or encounter any problems.**
- **You can contact the UCT Health Research Ethics Committee at 0214066492 if you have any concerns or complaints that have not been adequately addressed by the researchers.**